Measurement of the Validity of a Preschool Vision Screening Program

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ABSTRACT

Objectives. The validity (sensitivity and specificity) of a preschool vision screening program was measured over a 3-year period to determine how well strabismus and significant refractive errors could be detected.

Methods. Public health nurses were trained to administer tests of visual acuity, stereoacuity, and ocular alignment. Failure on any test, visual acuity of 6/9 or less, stereoacuity of less than 100 seconds of arc, or an apparent misalignment of the eyes resulted in referral to an eye care practitioner. An age-matched control was also referred. Analysis of practitioner reports used predefined study-based criteria for ocular abnormalities.

Results. More than 1100 children were screened each year. The annually calculated prevalence of vision problems ranged between 10.5% and 13.8%. The estimated sensitivity varied from 60.4% to 70.9% (specificity, 69.6% to 79.9%). The yield indicated that a very high percentage of children with vision problems were identified for the first time.

Conclusions. The validity of this screening is comparable to that of other school screenings. The limitations are predictable. Consideration should be given to replacing visual acuity tests with a rapid, objective measure of refractive error and ocular alignment. (*Am J Public Health.* 1999;89:193–198)

Vision screening programs are conducted for kindergarten (or primary school) entrants throughout Canada[1–4] and worldwide,[5–10] particularly where there are government-supported health programs. These school screenings typically involve measures of visual acuity and ocular alignment.

Visual acuity is a measure of how well adjacent visual stimuli can be separated. For the preschool child, the well-known Snellen Letter Chart has been replaced by letter-matching tests that avoid the need for the child to verbalize letters.[11] Ocular alignment typically is measured indirectly with a test of stereoacuity or directly with the Hirschberg test.

Stereoacuity measures the capacity of the visual system to resolve an object in depth. Stereoacuity is significantly degraded when the eyes are misaligned in strabismus. It is also compromised when visual acuity is degraded by refractive errors and amblyopia. The Hirschberg test provides a direct measure of ocular alignment—the symmetry of the corneal reflection as observed in the pupil of the left eye is compared with that of the right eye. In strabismus the reflection in the deviating eye is shifted in a predictable direction; however, the technique used in the Hirschberg test is insensitive to small angles (less than 5 degrees) of strabismus and requires considerable practice.

Examination of the Validity of Vision Screenings

Although vision screening programs have been in place for over a century,[12] there is little information about their validity. Both the Canadian and US government task forces[13–17] examined the published literature and concluded that so long as there was a lack of strong epidemiological evidence for or against school vision screening programs, vision screening should be continued until the value of detecting presymptomatic refractive defects in preschool- and school-aged children was better understood. Studies do show that the prevalence of vision problems is reduced when early vision screening programs are in place.[18,19]

Recently, through retrospective analysis, the positive and negative predictive values of a preschool vision screening program of children between the ages of 4.5 and 5.5 years in the province of Nova Scotia, Canada, were estimated at 50% and 96%, respectively.[20] Public health nurses used tests of visual acuity, tests of stereoacuity, and a visual inspection for ocular anomalies. The negative predictive value was determined from a small sample (n = 157) in which fewer than 2% of the children who passed the screening in 1990 were randomly selected to have a full ophthalmological examination. The positive predictive value was calculated from an even smaller retrospective sample of children (n = 36) who had failed the screening. This investigation constituted a step toward epidemiological analysis of vision screening, but it was limited by the small sample size and the potential for selection bias.

Epidemiological benchmarks for screening of school-aged children were provided by the Orinda Study,[21] in which several methods of vision screening for children

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aged 6 to 14 years were evaluated. One method, the Modified Clinical Technique, showed good validity (sensitivity and specificity in excess of 95%), but its usefulness as a public health screening test is limited because it requires the application of objective techniques that require the examiner to be highly skilled.[20] Another method, the Massachusetts Vision Kit, was administered by nurses; it provided a sensitivity of 55% and a specificity of 96.6%. The Massachusetts Vision Kit is a battery of tests that includes visual acuity (20/20 acuity is required to pass), eye alignment, and a plus-sphere test to identify hyperopia.[21] Failure on test and retest is required for referral.

In our study we examined the validity of a preschool screening program conducted by public health nurses in Oxford County, Ontario, Canada. The data analyzed covered a 3-year period. Initially, the screening was set up in accordance with guidelines published by the Ministry of Health of Ontario.[1] In the second year, the test selections were changed in an effort to improve the validity of the screening.

Methods

The Oxford County Screening Program

Vision screening tests were conducted by 6 to 9 public health nurses as part of the Preschool Health Fair Program over the period from 1992 through 1994. The program targeted all children registered for kindergarten in Oxford County in the spring preceding their entry into either junior or senior kindergarten. Approximately 50 health fairs were set up throughout the county from February through June. At each health fair, children's immunization records were reviewed and screenings were conducted in speech, hearing, and vision. Prior to vision screening, parental consent was obtained for inclusion of each child in this study. The rate of refusal was small but increased over the 3 years (from 0.6% to 3.2% to 7.8%).

Public health nurses were trained each year to conduct tests of visual acuity and ocular alignment.

Visual acuity test. A series of single letters were presented to the child at a 3-m distance (Cambridge Crowding Cards, Clement Clarke, London, United Kingdom). Each eye was tested separately through the use of plastic frames that occluded the eye not being tested. A total of 5 optotypes (X, O, T, V, and H) could be presented. Identical letters were placed before the child, who then needed only to point to the letter matching that shown by the examiner. Established norms published for this test[11,22] show that children between the ages of 3 and 5 years should score 6/6 or better in each eye. Accordingly, we classified 6/9, the next step below 6/6, as a "failure" for the visual acuity score.

Ocular alignment. In accordance with the guidelines of the Ministry of Health of Ontario, the Hirschberg test was conducted by having the child view a target (typically a finger puppet) set 40 to 50 cm away from the child. A small light source (a penlight) was placed coincident with the target. The position of the light's reflection in the pupil of the eye was compared between the left and right eyes. If the relative positions of the corneal reflexes in the 2 eyes were asymmetrical, the child was judged to have "failed" the test. This test was discontinued after the second year.

Stereoacuity. During the second year of screening, a test of stereoacuity was introduced (StereoFly, Titmus Optical Co, Petersburg, Va). In this test, objects are perceived in depth when polaroid glasses are worn. The child simply points to which object in a given row is "coming closer." The lateral disparities are varied in the targets so that the test provides a range of stereoacuities from very coarse (3600 seconds of arc) to adult levels (40 seconds of arc). A norm of 100 seconds of arc was found to be appropriate for the age group in this study.[23] The animal section of the Titmus Stereo Test was used. If stereoscopic appreciation was not noted for all the animals (100 seconds of arc), the child "failed" the test.

Referral

Children who failed any component of the screening were referred to an eye care practitioner of their choice. Children who failed to complete the screening were also referred; however, this number across the 3 years was low, an average of 1.8%. For each child who failed the screening, the nurses referred the next child who passed as a control (a "next in line" protocol). Parents and practitioners were masked to the screening results of all children referred. Communication of the study was made in advance to the eye care practitioners in Oxford County through letters and a general meeting.

Eye Care Practitioner Report

Practitioners were requested to file a report that included all of the major results from their examination. Personnel at the Oxford County Health Unit followed up all children who were referred by the study as to whether they had in fact seen an eye care practitioner and whether the practitioner's report had been received.

Data Analysis

The practitioner's report was matched with the child's screening result. Data from both sources were entered into a computer database (Epi Info, Centers for Disease Control, Atlanta, Ga). The validity of the screening program was measured by defining in advance which findings in the practitioner's report constituted a "visual problem." The goal of the screening was to detect strabismus and amblyopia and significant refractive errors. Accordingly, the following conditions were defined as being problems if found by the practitioner: (1) the presence of any strabismus, intermittent or constant, at any fixation distance; (2) anisometropia, defined as a difference of 1 diopter (D) or more between the refractive error (spherical equivalent) of the right eye and that of the left eye; (3) hyperopia of 2 D or more in any meridian in either eye; (4) myopia of 1 D or more along any meridian in either eye; and (5) astigmatism of more than 1 D in either eye.

The threshold of 2 D for the hyperopic refractive error was set on the basis of evidence linking this preschool level of hyperopia with amblyopia and strabismus.[22,24]

Results

The results of the study over its 3-year period shown in tabular form include the characteristics of the study population (Table 1); the screening results (Table 2); the estimated validity of the study (sensitivity and specificity) (Table 3); and the number and types of disorders detected and missed in the screening (Table 4).

More than 1100 children completed the vision screening each year and were enrolled into the study (Table 1). This represented from 92.2% to 99.4% of the total population that attended the health fairs. Data collected by the public health nurses in 1992 showed that 85% of new kindergarten registrants were screened. The mean age and sex distribution of the population over all 3 years were similar. It should be recalled, however, that in year 2, the stereoacuity test was introduced midway through the program, so that of the 1110 children enrolled in the study that year, 755 were screened with visual acuity, Hirschberg, and stereoacuity testing. Children tested in year 3 were screened with visual acuity and stereoacuity testing.

The percentage of children who failed the screening ranged from 25.5% to 34.7% during the 3-year period (Table 2). The number of "controls" referred was never exactly equal to the number of "failures." The percentage of practitioner reports received each

TABLE 1—Study Population Characteristics: Oxford County, Ontario, Canada, 1992–1994

	Year 1	Year 2	Year 3
Total	1174	1110	1150
Age, mean, mo	53.8	52.9	51.2
Age, range, mo	39–67	37–75	37–66
Sex, % boys	50.9	49.5	52.3

year was 81%, 84%, and 75.2%, respectively. Annual comparisons showed no statistically significant differences between the proportion received for children who failed the screening and for children referred as controls ($z \leq 0.81, P > .4$).

The positive predictive value (the proportion of children who failed the screening who showed a vision problem) and the negative predictive value (the proportion of children who passed the screening and showed no vision problem) can be directly calculated from the data for the 3 years of the study (Table 2). The positive predictive value varied from 21.6% to 32.3% and the negative predictive value from 92.6% to 95.3% over the 3 years.

The history taken during the screening determined whether the child was currently receiving any vision care. Given this, the yield (proportion of children newly identified as having a vision problem) could also be determined. Importantly, the yield across 3 years of the study is high where between 83% and 89% of the children identified as having a vision problem were so identified for the first time. The number of true positives each year (Table 4) was remarkably similar (70, 69, 74). Refractive errors newly detected over the 3 years ranged from 7.75 D of hyperopia to 10.75 D of myopia (highest meridian).

When the data are scaled to calculate the sensitivity and specificity,[25] the overall sensitivity of the screening varied from 60.4% to 70.9% for annual measures (Table 3). Sensitivity was highest (83.8%) during the second year of the study, when the estimate was based on only the 755 children tested with both the Hirschberg and the stereoacuity tests. The specificity was generally higher than the sensitivity, ranging from 69.6% to 79.7%. It was at its lowest (64.5%) in the second year, when both stereoacuity and Hirschberg tests were used. The estimated prevalence of visual problems in the screened population ranged from 10.5% to 13.8%.

Discussion

In the Oxford County vision screening we used a high standard of visual acuity, 6/6 (20/20) or better to pass the screening. If we had considered 6/9 as a pass, the sensitivity of the screening would be greatly reduced. Many of the children with problems detected by the screening would have been missed (41.4% to 64% depending on the year). These problems would have included strabismus and high amounts of astigmatism (over 3.00 D).

Comparison Between Hirschberg and Stereoacuity Tests

When the sensitivity of the screening with visual acuity and the Hirschberg test (year 1) is compared with that of the screening with visual acuity and stereoacuity (year 3), there is very little difference (61.9% vs 60.4%). There is a slight increase in specificity in year 3 (Table 3). The dramatic increase in sensitivity found in year 2 (when stereoacuity was added) may be a result of several factors. These factors may include bias due to the smaller sample size and the high number of overreferrals. The number of Hirschberg "failures" that were overreferrals increased dramatically in year 2, from 19 to 76. The Hirschberg test was dropped in year 3.

Several improvements were noted when the stereoacuity test replaced the Hirschberg test in year 3. The positive predictive value increased (Table 2). This increase is statistically significant; the 95% confidence interval for the positive predictive value in year 3 does not include the value calculated for year 1. Year 3 also had the lowest failure rate (Table 2). There were fewer overreferrals or false positives. No children in the control group had newly detected strabismus or amblyopia (Table 4).

The number of controls referred each year was never equal to the number of children who failed the screening, and their selection was not done on a strictly "next in line" criterion. It is suspected that several children who passed the screening but perhaps with difficulty were classified as controls. This type of selection bias will underestimate both the sensitivity and specificity of the screening test. Such controls had a greater likelihood of having a visual problem. The negative predictive value would also be underestimated. It must be recognized, however, that data analysis could be controlled at least to the extent that all children who were classified as controls had in fact passed the screening test.

Analysis of True Positives and False Negatives

Table 4 lists the visual problems (refractive and binocular) indicated by the eye care practitioners' reports and the classification of each problem as either a true positive or a false negative. During the 3 years, 41 children passed the screening but were found to have a visual problem (false negatives). Most of these underreferrals arose from limitations in the screening tests. More than half showed significant but not extreme amounts of hyperopia (from 2.00 D to 5.25 D). Hyperopia can be overcome by increasing the focusing power of the eye (accommodation), especially when the eye views monocularly. A child with hyperopia could pass the

TABLE 2—Results of Vision Screening: Oxford County, Ontario, Canada, 1992–1994

	Year 1	Year 2	Year 3
Failures, no. (%)	339 (28.9)	385 (34.7)	293 (25.5)
Controls, no.	312	297	240
Forms returned, no. (failures, controls)	527 (81.7%, 80.4%)	573 (82.9%, 85.5%)	405 (77.1%, 74.6%)
PPV, % (95% CI)	25.4 (20.2, 30.5)	21.6 (17.1, 26.2)	32.3 (26.2, 38.4)
NPV, % (95% CI)	93.6 (90.6, 96.6)	95.3 (92.7, 97.9)	92.6 (88.7, 96.5)
Yield (% of true positives newly diagnosed)	89	83	83.6

Note. PPV = positive predictive value; NPV = negative predictive value.

visual acuity test, but performance would depend on how well the child could sustain the increased level of focus. The greater the magnitude of hyperopia, the greater the difficulty in overcoming it and sustaining focus. This would explain why the frequency of false negatives declines as the magnitude of the hyperopia increases (Table 4).

Myopia cannot be overcome by accommodation, which is why very few myopic children passed the screening. The few who did may have squinted their eyes to reduce the blurred image. Astigmatism causes an uneven focus of light within the eye that cannot be cleared up by focusing alone. However, most of the astigmatic eyes that were missed in the screening had a "hyperopic" component, whereby part of the astigmatism could be overcome by focusing. Again, the higher the magnitude of astigmatism, the greater its effect on visual acuity, which accounts for the fact that very few children with a high degree of astigmatism (>2 D) passed the screening (Table 4).

After the stereoacuity test was added, only 1 child with intermittent strabismus passed the screening. Presumably, during the screening the strabismus was controlled. The combination of visual acuity and the Hirschberg test failed to identify 4 children with strabismus in year 1. Amblyopia, defined as a significant reduction in visual acuity in one eye compared with its fellow eye when both eyes have been optically corrected, was well captured by the screening. Only 1 false negative was found in the 3-year period. This is expected, since amblyopia is defined directly from measurements of visual acuity.

TABLE 3—Estimated Validity

	Year 1	Year 2 (With Stereoacuity)	Year 3
Sensitivity, %	61.9	70.9 (83.8)	60.4
Specificity, %	75.6	69.6 (64.6)	79.7
Prevalence, %	11.8	10.5	13.8

Comparison With Other Studies

The sensitivity of this vision screening method (60%) is comparable with that of other vision screenings performed by nurses where a high standard of visual acuity is used. The lower sensitivity (55%) reported for the Massachusetts Vision Kit would be expected because the Orinda Study classified a broader range of refractive error as vision problems. The higher specificity found with the Massachusetts Vision Kit may be associated with the difference in age groups screened (preschool vs school) as well as the test/retest method used in the kit.

The Enhanced Vision Screening Program[20] used a similar age group but a lower standard of visual acuity and stereoacuity in its screening ($6/9^{-3}$ for referral, stereoacuity < 200 seconds of arc). The Enhanced Vision Screening Program reported a negative predictive value similar to the one we found, but a somewhat higher positive predictive value of 50%. However, our estimate for the positive predictive value lies within their 95% confidence interval.

TABLE 4—Vision Disorders Detected and Missed

	Year 1		Year 2		Year 3	
	True Positives	False Negatives	True Positives	False Negatives	True Positives	False Negatives
Refractive errors						
Total (eyes)[a]	124	30	132	16	128	24
Hyperopia (range)	2.00 to 7.00	2.00 to 2.25	2.00 to 7.25	2.00 to 3.75	2.00 to 7.75	2.00 to 5.25
2.00 to 3.75	36	9	34	9	41	7
4.00 to 5.75	10		10		14	5
6.00 to 7.75	5		1		7	
Myopia (range)	−1.00 to −3.50	−1.00	−1.00 to −7.00		−1.00 to −10.75	−1.00
−1.00 to −2.75	20	1	14		15	2
−3.00 to −4.75	2				4	
−5.00 or more			1		2	
Astigmatism (range)	1.25 to 4.00	1.25 to 1.75	1.12 to 4.50	1.25 to 2.00	1.25 to 4.50	1.25 to 2.50
1.25 to 2.00	23	2	24	3	27	6
2.25 to 3.00	13		10		6	1
>3.00	9		3		3	
Binocular problems						
Total (children)[b]	70	16	69	12	74	13
Anisometropia (range)	1.00 to 3.00	1.00	1.00 to 7.00	0	1.00 to 5.00	2.00
1.00 to 2.00	5	3	8		7	1
2.25 to 3.00	6		1			
>3.00			1		4	
Amblyopia (total)[c]	12	1	10	0	14	0
1-line difference in visual acuity	7	1	10		6	
Strabismus (total)	14	4	15	2	12	0
Esotropia	7	2	12		10	
Exotropia	3	2	3	2	1	
Hypertropia			1			

[a]Includes the number of eyes for which refractive error results were provided by the eye care practitioners. Children with their refractive errors corrected prior to the screening were not included. The total is the number of eyes.
[b]Includes the total number of children in the true positive and false negative categories. The total is the number of children.
[c]Includes all children identified with amblyopia by practitioner's report as well as those identified by a one-line difference between eyes in aided visual acuity.

Future Considerations

Vision screening using tests of visual acuity and ocular alignment alone does not achieve a sensitivity or specificity above 95%. Only with a battery of tests approaching that of the Modified Clinical Technique can the validity attain 95%. It would appear that a different screening paradigm should be considered. Visual acuity in itself is not specific to a given ocular problem and is degraded by a number of visual conditions, with refractive errors being the most frequent. A more direct screening method would be to employ tests that rapidly detect refractive error in the preschool population. Photorefractive methods have been developed[22,26–35] that, because they are photographically based, provide rapid measures of refractive error in a manner suitable for use with preschool children. Hyperopia could be readily identified by testing with the child wearing a partial-spectacle correction for hyperopia. We suggest that a controlled study be conducted where photorefractive methods are employed and be compared with visual acuity and stereoacuity testing.

Conclusions

Vision screening of preschool children can be delivered effectively by public health nurses as part of the overall screening programs conducted in a health fair design. More than 10% of the preschool-aged population had significant vision problems. Most of these problems were uncorrected refractive errors that had not been previously detected. The yield in this study was surprisingly high, indicating that, even in a country with government-subsidized vision care, children with identifiable vision problems have not been detected prior to school entry. On this point alone, the importance of screening is supported. The validity measures are somewhat similar to previous screenings by nurses.[21,36] The weakness in the screening is predictable, in that children with hyperopic refractive errors can overcome them by adjusting the ocular focusing mechanism (accommodation). While some instances of strabismus were missed after stereoacuity testing was introduced, these cases were typically intermittent and therefore would not be a serious concern with regard to future development of amblyopia.[37]

In summary, the yield of vision problems detected by public health nurse screening supports the screening's continuation. New methods of testing ought to be considered in order to improve screening validity and reduce the cost to the health care system. The consideration of photography-based procedures is strongly recommended. □

Contributors

This study was a collaborative effort between the Oxford County Board Health in Woodstock, Ontario, Canada, and the University of Waterloo in Waterloo, Ontario, Canada. The screening program and follow-up were administered by Beth Martin and Lynda Bryant of the Oxford County Board of Health. The analysis of the screening results and the writing of the paper were primarily conducted by William Bobier and Barbara Robinson of the University of Waterloo.

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